Paper No. 99-2054
An ASAE Meeting Presentation

SURFACE RUNOFF FROM LEPA AND SPRAY IRRIGATION OF A SLOWLY-PERMEABLE SOIL

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Written for Presentation at the
1999 ASAE/CSAE Annual International Meeting
Sponsored by ASAE

Sheraton Centre Toronto Hotel
Toronto, Ontario Canada
July 18-21, 1999

Summary: Runoff due to LEPA and spray sprinkler irrigation of diked and undiked furrows was measured from 20-m long plots of Pullman clay loam, a slowly-permeable soil. An irrigation control treatment received 100% irrigation for maximum grain yields, and deficit irrigation treatments received 0, 40, 60 and 80% of the fully irrigated amount on the same day. Runoff was measured volumetrically in steel tanks from three wheel track and three non-wheel track furrows in each plot. With 100% irrigation, runoff amounts for the sprinkler method/furrow diking combinations were 0% for Spray/Diked, 12% for Spray/Undiked, 22% for LEPA/Diked and 52% for LEPA/Undiked. For the LEPA sprinkler method, grain sorghum yields were significantly reduced due to runoff with undiked furrows during a near-normal rainfall year and with both diked and undiked furrows during a drought year.

Keywords: Runoff, Sprinkler, Irrigation, LEPA, Spray, Diked, Furrows

INTRODUCTION

With mechanical-move sprinkler irrigation systems, instantaneous application rates are larger and irrigation depths are smaller than with traditional hand move systems. Impact sprinklers installed on hand move pipelines were traditionally used with application rate less than the soil infiltration rate to prevent surface runoff (Christiansen, 1942). In recent years, the height and wetted diameter of sprinkler patterns on mechanical-move sprinkler systems have been reduced to decrease droplet evaporation and drift and system operating pressures. As this has occurred, instantaneous sprinkler application rates have often exceeded soil infiltration rates, especially for slowly-permeable soils. With hand-move sprinkler systems, irrigation depths were often in the 100 to 200-mm range to refill the entire plant rooting zone and reduce the number of times the irrigation pipe had to be moved. With mechanical-move sprinkler systems, smaller irrigations in the range of 20 to 40 mm are applied more frequently. The soil surface may then be relatively wet and not have the larger intake rate typical of a drier soil. Both the larger application rates and the reduced soil intake rates increase the opportunity and likelihood of surface runoff.

The quantity of runoff from sprinkler irrigation depends on both the potential for runoff and factors aggravating or mitigating the runoff condition. Potential runoff is defined as the portion of sprinkled water that is applied in excess of the soil intake rate (Kincaid et al., 1969). Intake rate is primarily a function of the soil texture and soil surface condition at the time of irrigation. Classical infiltration theory assumes that the soil surface is instantly saturated; yet sprinkler application like smaller rainfall rates may not initially saturate the soil. A modified intake function is required to compensate for the interval, often referred to as the time to ponding, before the soil surface is saturated. After ponding and runoff start, the severity of runoff depends on both the magnitude of the potential runoff and factors such as surface slope, soil surface roughness and residue cover. Kincaid et al. (1969) presented data indicating larger runoff with the irrigation system moving upslope as compared to moving downslope. They reasoned that in the downslope condition, larger cumulative intake occurs before the potential runoff condition starts.

Soil surface modification and crop residues enhance soil infiltration and compensate for sprinkler application rates exceeding the soil intake rate. These techniques may be needed with spray irrigation but are mandatory with LEPA irrigation. "LEPA was designed to be, for the most part, independent of soil intake rate" (ASAE, 1998). Instead of a design based on the soil intake rate, LEPA design is based on the application volume per irrigation not exceeding the surface storage volume. Although the wetted diameter of spray heads greatly exceeds that of LEPA, surface runoff may still be large enough to reduce the application efficiency and uniformity.

The effectiveness of soil surface modification and crop residues depends primarily on the sprinkler method, soil type and surface slope. Aarstad and Miller (1973) used basin tillage and hay incorporated at 4.5 Mg/ha or mulched at 1.8 Mg/ha to control surface runoff from high pressure impact sprinklers on center pivot sprinkler systems. With basin tillage, runoff was reduced to only 1% of applied water. Without soil surface modification, runoff percentages were 11 and 16% for two silt loam soils with 3% slope and 17 and 41% for two loam soils with 7% slope. Runoff was less than 6% with the residue treatments, except for the hay mulch of the 7%

slope that had 30% runoff. Michelson and Schweizer (1987) evaluated till-plant systems for reducing runoff from high-pressure (345 kPa) and low-pressure (138 kPa) center pivot sprinkler systems. For three till-plant systems, runoff from low-pressure averaged 30% larger than from high-pressure. Both runoff and soil erosion were best controlled by the least amount of tillage and by surface layer incorporation of residue before planting. Kranz and Eisenhauer (1990) used a rainfall simulator to irrigate a 1.0% slope Hastings silt loam at 139mm/h and a 10% slope Nora silt loam at 119 mm/h. For 50-mm irrigations, the runoff amount with conventional and implanted reservoir tillage was 2.6 and 2.7 mm for the 1% slope and 12.4 and 3.9 mm for the 10% slope. Spurgeon et al. (1995) evaluated the effect of the LEPA bubble and flat (in-canopy) spray sprinkler methods and conventional, basin or implanted reservoir tillage on corn yields. For the three respective tillage treatments, their data analysis showed yield reductions of 1.46, 1.60 and 0.90 Mg/ha for each 1% increase in slope with the LEPA bubble method and 0.71, 0.85 and 0.16 Mg/ha with flat spray method. In evaluating a LEPA-equipped center pivot sprinkler system, Buchleiter (1992) measured runoff amounts exceeding 30% of applied water for a 3% slope and 55% of applied water for a 8% slope.

The objectives of the field study reported here were to measure surface runoff from full and deficit irrigation of a slowly-permeable soil with the LEPA and spray sprinkler methods and to measure the effect of the runoff on soil water storage and grain sorghum yields.

PROCEDURE

The research was conducted at the USDA Conservation and Production Research Laboratory, Bushland, TX (35°11' N Lat, 102°06' W Long, 1170 m M.S.L. elevation) during the 1997 and 1998 grain sorghum seasons. The Pullman clay loam soil at the site is a fine, mixed, thermic torrertic paleustoll with a dense B21t subsoil from about 150 to 400 mm and a calcic horizon extending from the 1.5 to 2.0-m depths. For the upper 1.47-m profile, Unger and Pringle (1981) measured 167 mm of soil water storage between the -0.033 and -1.5 MPa water potentials. The research field had a uniform slope of 0.0025 m/m along the furrows and 0.0022 m/m perpendicular to the furrows.

Experimental Design

The LEPA bubble and Mid-Elevation Spray Application (MESA) sprinkler methods were evaluated with five irrigation amounts ranging from 0 to 100% of soil water replenishment. Full irrigation or 100% soil water replenishment is designated as I_{100}. Deficit irrigation with 0, 40, 60 and 80% of the full irrigation amount is designated as I_0, I_{40}, I_{60} and I_{80}, respectively. Grain sorghum was planted on 0.76-m spaced beds, and the two sprinkler methods were used with and without basin tillage (furrow) dikes. Field plots were arranged in a randomized block design with irrigation amount treatments being the blocks and sprinkler methods being randomized within each block. The twenty treatment combinations were replicated three times, once under each span of the irrigation system. Plot size was twelve 0.76-m rows wide along the mainline of the lateral move irrigation system by 20 m long in the direction of the furrows.

Soil water was measured gravimetrically on all plots for determining seasonal soil water depletion and with a neutron meter on the I_{100}, LEPA/Diked plots for scheduling irrigations. The gravimetric soil water samples were collected in 0.30-m increments to the 1.8-m depth after planting and at harvest. The neutron soil water measurements were made weekly in 0.2-m increments to the 2.3-m depth except when rainfall made irrigation unnecessary. These measurements were made with a locally field-calibrated CPN Model 503DR[1] neutron moisture meter (Evett and Steiner, 1995). The target soil water level for irrigation scheduling was 75% of the plant available amount in the 1.4-m profile, which is about 410 m of total water for the Pullman clay loam soil. This is a high soil water level for grain sorghum and would be a moderate to high level for corn. Both the gravimetric and neutron soil water measurements were collected on one of the two center rows of the 12-row wide plots.

Irrigation Equipment

Irrigations were applied with a 3-span, hose-fed Valmont Model 6000 lateral move irrigation system supplied with pressurized water from a surface reservoir. Each span was 39 m long and provided space for forty-eight, 0.76-m wide beds and furrows. Both the LEPA and MESA sprinkler devices were spaced 1.52-m apart to apply water into or above alternate furrows. The LEPA double-ended socks were attached to Senninger Super Spray heads and pulled through the furrows with the full length of the sock in contact with the ground. The MESA sprinkler devices were Senninger Super Spray heads with flat, medium-grooved deflector plates. These sprinklers were positioned about 1.6 m above ground or about 0.3 m above the height of the mature grain sorghum crop. The Senninger Super Spray heads for both LEPA and MESA were regulated with 41-kPa pressure regulators and discharged through 6.75-mm nozzles. Irrigation amount was varied by adjusting the speed of the lateral move irrigation system with the CAMS controller.

Runoff Measuring Equipment

Irrigation runoff was collected at the lower end of the plots and pumped into tanks for volumetric measurement. The 20-m-long plots were all diked at each end, and three wheel track and three non-wheel track furrows were isolated for runoff measurement. The runoff water was collected in sumps constructed of 300-mm diameter, PVC irrigation pipe and then pumped into the tanks with submersible pumps and 38-mm polyethylene pipe.. The tanks were standard, circular livestock watering tanks with diameters ranging from 2.13 to 2.44 m and volumes ranging from 2060 to 2700 L. The largest tanks were used for the LEPA/Undiked plots, and the smallest ones were used for the Spray/Diked plots. We have never observed runoff from the Spray/Diked combination so no runoff measuring equipment was required for these plots. The diameters of all tanks were individually measured to calculate tank areas. Water depths at the four quadrants of the tanks were averaged for each runoff measurement.

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[1]The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation or exclusion by the USDA-Agricultural Research Service.

Cultural Practices

Cultural practices were similar to those used for high-yield, sprinkler-irrigated grain sorghum in the Southern Great Plains. Table 1 lists fertility, pesticide and crop variety information plus planting and harvesting dates for the two crop years. Both crops were grown on land that had been fallowed with sweep or disk tillage during the previous year to accumulate soil water and hopefully to reduce weed, soil-borne disease and insect populations. All tillage and planting was done with six, 0.76-m-row wide farm machinery to match the 48-row-wide spans of the irrigation system. After anhydrous ammonia fertilizer was chiseled in with 0.76-m spaced chisels during the early spring (table 1), the plot area was tandem disked and bedded with a disk bedder. The beds were then firmed and shaped with a rolling cultivator, and the grain sorghum was planted with a John Deere Max-Emerge planter. When the sorghum was about 0.2 m tall, it was cultivated with a rolling cultivator. The furrow-diked plots were then diked with a Bingham Brothers trip and roll diker. During both years additional nitrogen in the liquid urea form was applied with the irrigation water (table 1).

Grain yields were measured by either combine harvesting or hand harvesting. In 1997, a 1.52-m wide Hagy plot combine was used to harvest the full length of the four center rows of each plot. In 1998, hand samples were collected from 9.1 m of the center rows of each plot and threshed with the Hagy combine. After weighing the grain samples, a sub-sample was dried to determine grain moisture content, and duplicate or triplicate weights of 500 seed were determined. The grain yields and water use efficiencies presented here are based on 14% grain moisture content (wet basis).

Irrigation Procedure

Dates and amounts of preplant and emergence irrigation for the two crop years are listed in table 1. In 1997, an emergence irrigation and a small irrigation to soften the soil crust were sufficient to obtain germination and crop establishment. Drought conditions existed during the spring of 1998, and two preplant irrigations were required in addition to two emergence irrigations. Preseason and emergence irrigation was uniformly applied with Senninger Super Spray heads to obtain crop emergence with the minimum amount of irrigation water. The first seasonal irrigation after furrow diking was also applied with spray heads to settle the soil in the furrow dikes before LEPA irrigating.

The dates and amounts of the I_{100} irrigations are illustrated in figure 1, and seasonal irrigation amounts for all irrigation treatments are listed in table1. The target I_{100} irrigation amount was 25 mm, but actual irrigation amounts were calculated from the time of irrigation over each plot. The irrigation frequency for the two years reflects the rainfall distribution. With near normal rainfall during late May and early June of 1997 the first seasonal irrigation was applied on 24-Jun. Later, an interval of above average rainfall during Late July and early August7 made seasonal irrigation unnecessary for a 17-d interval in early August. With the limited amount of rainfall in 1998, the first seasonal irrigation was applied on 16-Jun and 21 additional irrigations were applied ending on 31Aug. These irrigations were generally applied twice a week from mid-June until the 31 Aug irrigation cutoff.

Tables 2 and 3 list values for total water use, seasonal water use efficiency (WUE) and irrigation water use efficiency (IWUE). Total water used is defined as the sum of seasonal soil water depletion, irrigation during the growing season and rainfall. In includes the runoff amounts for an equal evaluation of the total irrigation water applied. WUE and IWUE, both reported as kg/m^3, will be used to evaluate the efficiency of the irrigation amounts, sprinkler methods, and furrow diking. WUE will be reported as grain yield divided by total water use, and IWUE will be reported as irrigated grain yield minus the I_0 grain yield divided by seasonal irrigation amount.

RESULTS

Runoff

Runoff was measured during 13 of 15 seasonal irrigations in 1997 and 16 of 22 seasonal irrigations in 1998. Runoff as a percent of total irrigation applied during the measured irrigations is illustrated in figure 2. For all treatments, runoff was essentially zero for I_{40} but then increased with irrigation depth for the three larger irrigation amounts. For the Spray/Undiked treatment, runoff was minimal with I_{60} but then increased to an average of 7% for I_{80} and 12% for I_{100}. Runoff for the LEPA/Diked treatment was approximately twice that of the Spray/Undiked treatment with average runoff percentages of 6, 12 and 22% for I_{60}, I_{80} and I_{100}, respectively. Runoff percentages for the LEPA/Undiked treatment illustrated the absolute necessity of basin or implanted reservoir tillage for LEPA irrigation. From negligible runoff with I_{40}, runoff percentages increased to 37% for I_{60} and 46 and 52% for I_{80} and I_{100}.

Runoff amounts increased with time during the growing season for the LEPA and the Spray/Undiked treatments. With recently-tilled soil and new furrow dikes, there was little or no runoff from any treatments during the first three or four irrigations. The largest temporal increase occurred with the LEPA/Diked treatments that were affected by both reduced soil infiltration and furrow dike erosion. The smallest increase was with the Spray/Undiked treatments.

Runoff amounts did not vary appreciably or consistently from irrigating in either the upslope or the downslope direction. In 1997, runoff amounts were slightly larger with the irrigation system moving downslope but in 1998 this trend reversed.

Soil Water

Changes in soil water storage for the I_{100} irrigation plots reflect the effect of runoff from the plot areas. As illustrated in figure 3, the LEPA/Diked irrigation control treatment had little change in soil water during the 1997 cropping season. Soil water in both spray treatments was similar to the control treatment. In the LEPA/Undiked treatment, however, soil water depletion occurred throughout most of the growing season except for the 19 Aug measurement. Then, early-August rainfall caused the soil water contents for all irrigation treatments to return to near their early season level.

The extreme drought conditions in 1998 caused a different pattern in soil water storage (fig. 4). Even with 22 seasonal irrigations, soil water in the LEPA/Diked treatment declined except for a short interval during mid-August. Soil water storage in the Spray/Undiked treatment was the most constant, and in the Spray/Diked treatment, soil water storage increased, especially during the later half of the growing season. A major decrease in soil water storage occurred for the LEPA/Undiked treatment with only a minor recovery from the August rainfall.

Profile soil water after the last seasonal irrigation is illustrated in figures 5 and 6 for the I_{100} irrigation treatment. On 4 Sep 97 soil water for both spray treatments and the LEPA/Diked treatment was similar, but for the LEPA/Undiked treatment it was much lower. For example, in the 1.4-m profile, the LEPA/Diked and Spray/Diked treatments had 49 and 56 mm more soil water than the LEPA/Undiked treatment. The 6 Sep 98 soil water contents are much different than those at the end of the 1997 growing season. Both spray treatments had larger soil water contents than the LEPA treatments, and for the Spray/Diked treatment the difference was especially large. For the 1.4-m profile, soil water contents for the Spray/Diked and Spray/Undiked treatments were 118 and 59 mm larger than for the LEPA/Undiked treatment. For the Spray/Diked treatment, the soil water content of 0.31 m^3/m^3 at the 2.3-m depth strongly suggests that deep percolation may have occurred.

Grain Yields and Water Use Efficiency

Grain yields are illustrated in figures 7 and 8 for the two respective years. In 1997 grain yields for the I_0 through I_{80} irrigation amounts and the sprinkler methods were all significantly different. There was no significant yield difference between diked and undiked furrows. Significant interactions ($p \leq 0.05$) occurred between the irrigation amounts and methods and between the methods and diking. The reduced grain yields with the LEPA/Undiked treatment illustrated the effects of large runoff amounts and reduced soil water storage. The similar grain yields with 80 and 100% irrigation of the LEPA/Diked treatment illustrate the effect of the increased runoff percentage for 100% irrigation.

Reduced grain yields in 1998 show the effects of extreme drought and heat during the early part of the growing season. Irrigation amounts were significantly different in the I_0 to I_{60} range, but neither the I_{60} and I_{80} or the I_{80} and I_{100} yields were significantly different. The LEPA and spray sprinkler methods were also significantly different. As in 1997, there was no significant difference between the diked and undiked treatments. For the spray method, yields continued to increased over the full range of irrigation but at a lesser rater for irrigation amounts larger than 40%. For the LEPA method, maximum yields occurred with 40% irrigation and then decreased slightly for the other irrigation amounts.

WUE and IWUE for the two crop years are listed in tables 2 and 3. For both years, WUE varied significantly among irrigation amounts. In 1997, the largest water use efficiencies were with I_{80} and I_{100}, but in 1998 the largest water use efficiency was with I_{60}. In the drought year of 1998, WUE was significantly larger with the spray method than the LEPA method and with the diked than the undiked furrows. IWUE also varied significantly among the irrigation amounts . For both years it was largest with I_{40} and smallest with I_{100}. In 1998, IWUE was also significantly larger for the spray method than the LEPA method.

In 1997 seed mass increased directly with irrigation amount but the I_{60} to I_{80} and I_{80} to I_{100} increments were not significantly different. In 1998, the seed mass with I_{40} was significantly larger than for the other irrigation amounts. Seed mass with the diked and undiked furrows was also significantly different in 1998.

Soil water depletion and total water use are listed in tables 2 and 3 for the two respective years. In 1997, seasonal soil water depletion decreased with irrigation amount but averaged 100 mm or more for all irrigation amounts. Total water use ranged from 401 mm for I_0 to 705 mm for I_{100}. In 1998, soil water depletion for I_0 and I_{40} was similar to that in 1997. For larger irrigation amounts, it was much smaller than the previous year because of the small or negative depletion of the Spray/Diked treatment. Total water use in 1998 ranged from 250 mm for I_0 to 731 mm for I_{100}.

DISCUSSION

This study quantifies the large amounts of runoff that can occur with LEPA and spray irrigation of a slowly-permeable soil. The large amounts of runoff occurred even with the relatively flat slope of 0.25% in the direction of the furrows. The largest runoff potential occurs when irrigating to maintain soil water levels in the upper quarter of the plant available range. For large on-farm center pivots, much of the runoff measured in this study would be redistributed within the field. The field areas receiving the runoff would be over-irrigated and the excess water would either be lost to deep percolation or remain in the soil profile at harvest.

The grain sorghum yields in 1997 are more typical of high-yield, irrigated production in the Southern High Plains than those in 1998. The I_{100} yields with the spray method averaged 9.58 Mg/ha in 1997, an above average yield for the area. Grain yields with the LEPA/Diked treatment were similar to those of the spray method except for I_{100}. Only, the LEPA/Undiked treatment with large amounts of runoff had reduced yields for the three larger irrigation amounts. In 1998, the grain yields with I_{40} were similar to those in 1997. For the larger irrigation amounts, there were only small incremental yield increases for the spray method and small reductions for the LEPA method. Because of extreme heat and drought, the grain sorghum did not reach its yield potential as it did in 1997.

The I_{100} soil water and grain yield data illustrate that rainfall during the growing season tends to mitigate the effects of runoff. In 1997 for example, soil water in the I_{100}, LEPA plots was beginning to be depleted by late July. The 100 mm of rainfall in early August then raised or maintained the soil water for all treatments through mid August. In 1998, major soil water depletion began in early July for all treatments except the Spray/Diked one. A slight recovery from the August rainfall occurred for all treatments, but major depletion then resumed for the LEPA treatments. The grain yield reductions due to runoff increased as the percentage of evapotranspiration supplied by irrigation increased.

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Table 1. Agronomic and irrigation data for the two grain sorghum crops.

Variable	1997	1998
Fertilizer applied to I_{100}	140 kg(N)/ha preplant 50 kg(N)/ha with irrigation	140 kg(N)/ha preplant 40 kg(N)/ha with irrigation
Herbicide applied	Atrazine 2.2 kg(AI)/ha	Atrazine 2.2 kg(AI)/ha
Grain sorghum variety	Pioneer 8212Y	Pioneer 8212Y
Planting date	23 May	18 May
Harvest dates	24 Sept	25 Sept
Preplant irrigations	None	11 May - 25 mm 13 May - 25 mm
Emergence irrigations	27 May - 25 mm 2 Jun - 6 mm	21 May - 25 mm 27 May - 10 mm
First seasonal irrigation	24 Jun	16 Jun
Last seasonal irrigation	2 Sep	31 Aug
I_{40} Seasonal irrigation	173 mm	236 mm
I_{60} Seasonal irrigation	252 mm	357 mm
I_{80} Seasonal irrigation	329 mm	471 mm
I_{100} Seasonal irrigation	398 mm	578 mm

Table 2. Seasonal soil water depletion, total water use, water use efficiencies and seed mass for 1997.

Irrigation Amount	Sprinkler Method	Furrow Dike	Soil Water Depl. mm	Total[5] Water Use mm	WUE[6] kg/m³	IWUE kg/m³	Seed Mass mg/seed
0%			177	401	0.42	---	17.4
40%	LEPA	Diked	116	488	1.25	2.54	19.1
	LEPA	Undiked	139	512	1.23	2.65	21.3
	Spray	Diked	127	500	0.96	1.80	20.0
	Spray	Undiked	155	527	1.09	2.34	20.2
60%	LEPA	Diked	126	577	1.29	2.28	22.5
	LEPA	Undiked	144	596	0.97	1.61	21.3
	Spray	Diked	144	595	1.13	2.00	21.7
	Spray	Undiked	154	605	1.18	2.16	24.3
80%	LEPA	Diked	121	649	1.33	2.11	23.4
	LEPA	Undiked	125	653	1.15	1.76	21.9
	Spray	Diked	101	629	1.44	2.23	25.5
	Spray	Undiked	114	642	1.39	2.20	25.1
100%	LEPA	Diked	98	696	1.20	1.67	23.0
	LEPA	Undiked	118	715	1.01	1.39	23.6
	Spray	Diked	83	680	1.42	2.00	25.9
	Spray	Undiked	133	730	1.30	1.96	25.1
			Irrigation Amount Averages				
0%			177	401	0.42c	---	17.4
40%			135	507	1.13b	2.33b	20.2
60%			140	593	1.14b	2.01a	22.4b
80%			117	646	1.33a	2.08b	24.0ab
100%			108	705	1.23ab	1.75a	24.4a
			Sprinkler Method Averages				
	LEPA		134	568	1.02a	2.00a	21.1a
	Spray		137	571	1.08a	2.09a	22.2a
			Diking Averages				
		Diked	128	562	1.08a	2.08a	21.6a
		Undiked	143	578	1.02a	2.01a	21.8a

[5] Includes soil water depletion, irrigation and 199 mm of precipitation during the growing season.
[6] Averages followed by the same letter are not significantly different ($p \leq 0.05$)

Table 3. Seasonal soil water depletion, total water use, water use efficiencies and seed mass for 1998.

Irrigation Amount	Sprinkler Method	Furrow Dike	Soil Water Depl. mm	Total[7] Water Use mm	WUE[8] kg/m³	IWUE kg/m³	Seed Mass mg/seed
0%			145	250	.61	---	18.7
40%	LEPA	Diked	103	444	1.24	1.68	21.0
	LEPA	Undiked	154	495	1.12	1.71	22.4
	Spray	Diked	145	486	1.14	1.69	23.3
	Spray	Undiked	152	493	1.22	1.91	24.1
60%	LEPA	Diked	40	502	1.12	1.15	17.0
	LEPA	Undiked	107	569	0.92	1.04	20.4
	Spray	Diked	65	527	1.24	1.40	18.1
	Spray	Undiked	74	536	1.14	1.27	18.5
80%	LEPA	Diked	29	605	0.82	.73	17.6
	LEPA	Undiked	89	665	0.85	.88	19.8
	Spray	Diked	36	612	1.12	1.13	18.3
	Spray	Undiked	17	593	1.03	0.97	17.0
100%	LEPA	Diked	53	736	0.63	0.54	15.3
	LEPA	Undiked	92	775	0.61	0.56	17.5
	Spray	Diked	-38	645	1.16	1.03	18.9
	Spray	Undiked	88	770	0.91	0.94	19.1
			Irrigation Amount Averages				
0%			145	250	0.61	---	18.7a
40%			127	480	1.18c	1.75	22.7
60%			57	533	1.10bc	1.22	18.5a
80%			23	619	0.96ab	0.93	18.2a
100%			49	731	0.83a	0.77	17.7a
			Sprinkler Method Averages				
	LEPA		96	530	0.85	1.04	18.8a
	Spray		82	516	1.02	1.29	19.5a
			Diking Averages				
		Diked	71	504	0.97	1.17a	18.7
		Undiked	108	541	0.90	1.16a	19.6

[7] Includes soil water depletion, irrigation and 105 mm of precipitation during the growing season.
[8] Averages followed by the same letter are not significantly different ($p \leq 0.05$)

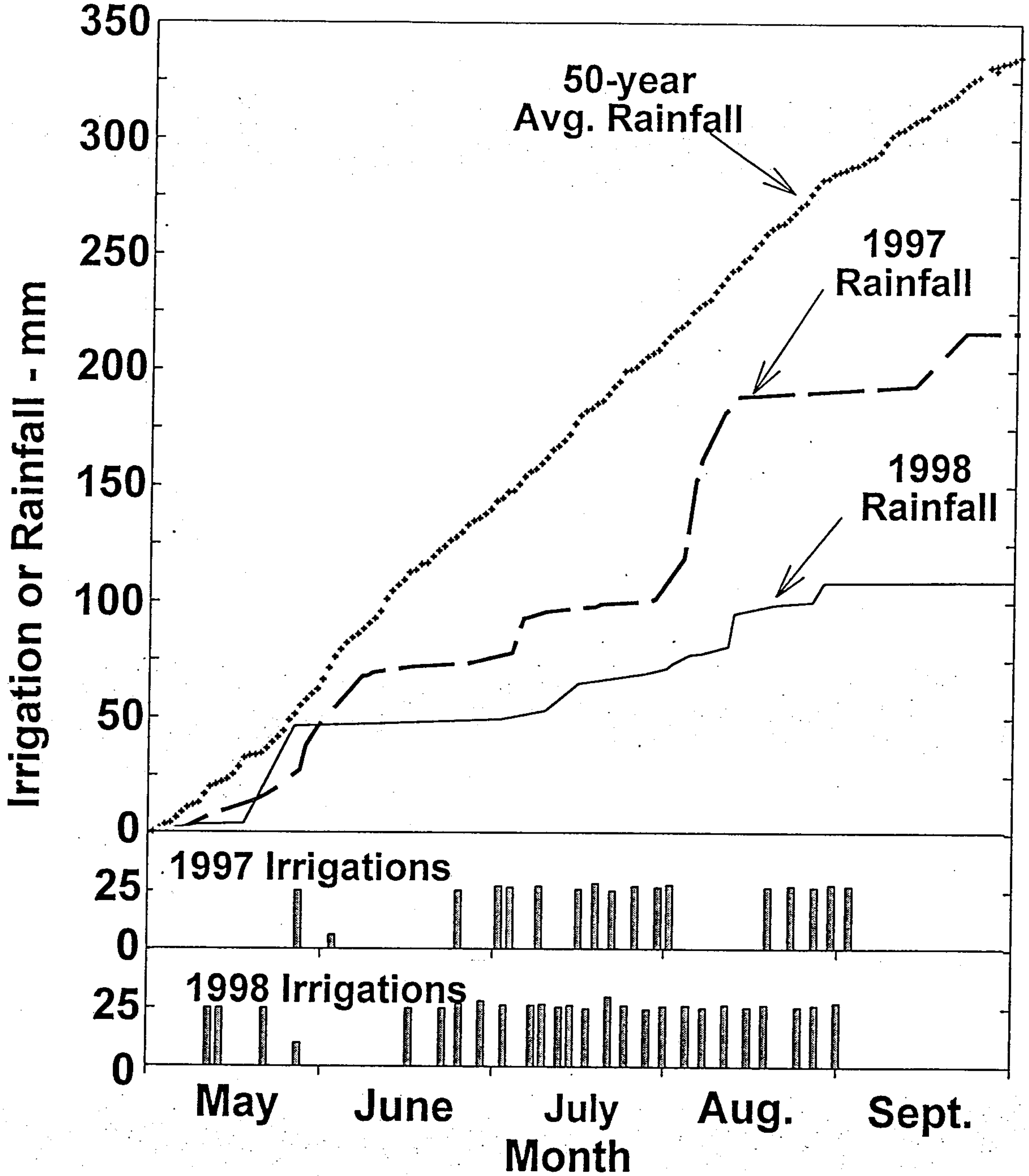

Figure 1. Irrigation and rainfall amounts for the 1997 and 1998 grain sorghum seasons and 50-y average rainfall for the grain sorghum season.

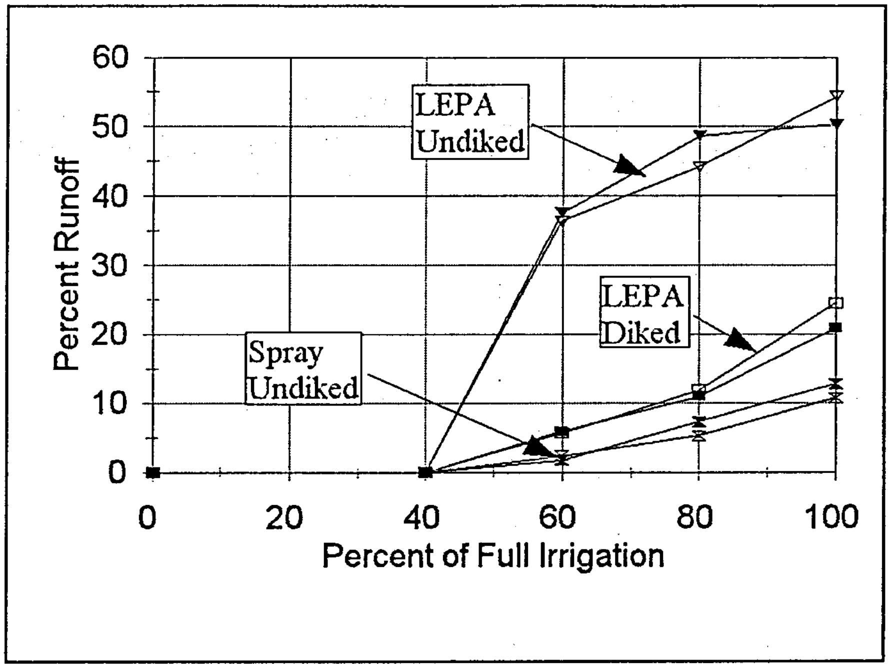

Figure 2. Seasonal runoff as a percent of sprinkler applied water. Solid symbols are for 1997, and open symbols are for 1998.

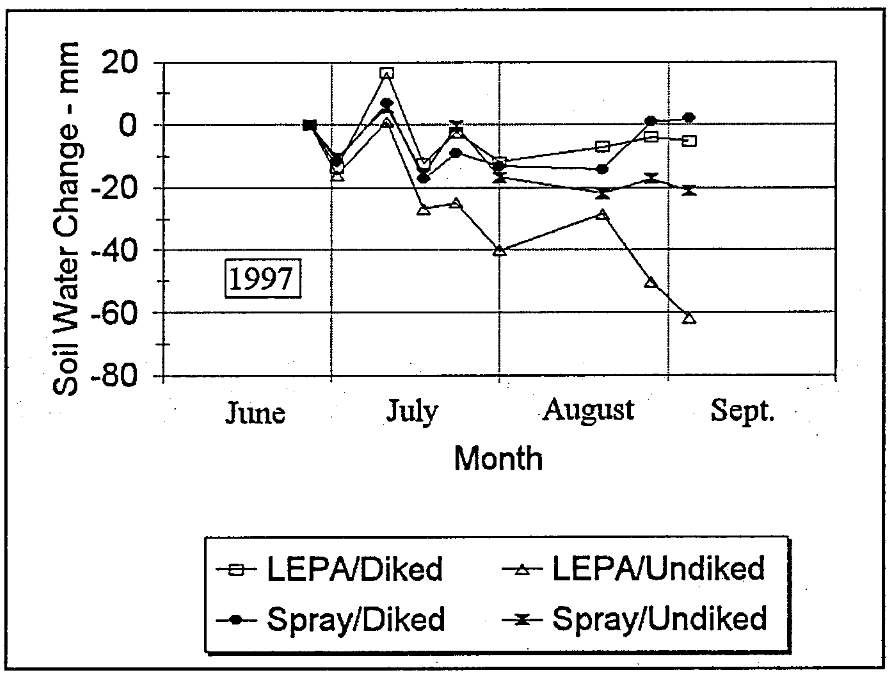

Figure 3. Change in soil water in the1.4-m profile of the I_{100} plots during the 1997 irrigation season.

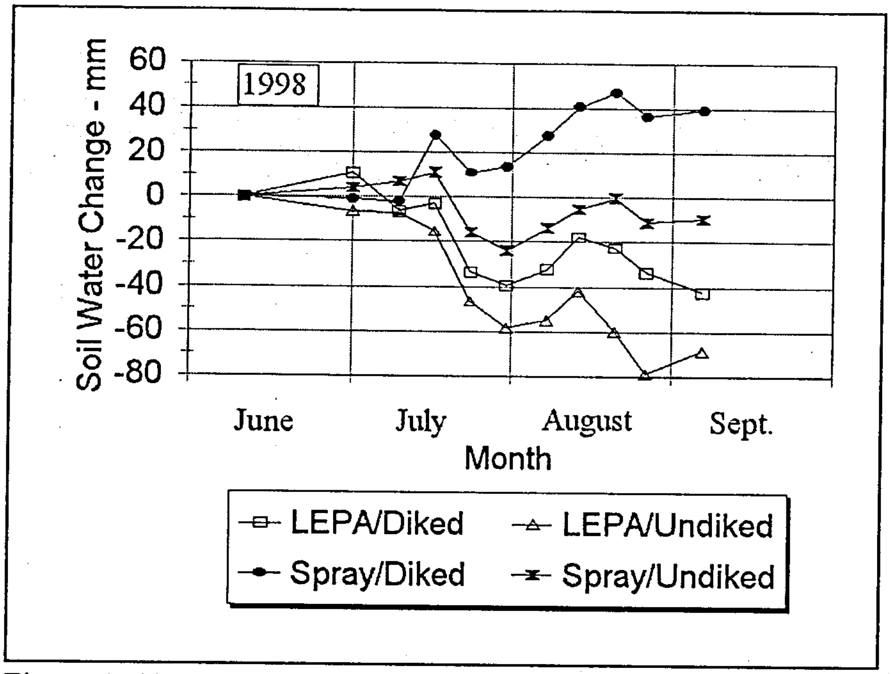

Figure 4. Change in soil water in the 1.4-m profile of the I_{100} plots during the 1998 irrigation season.

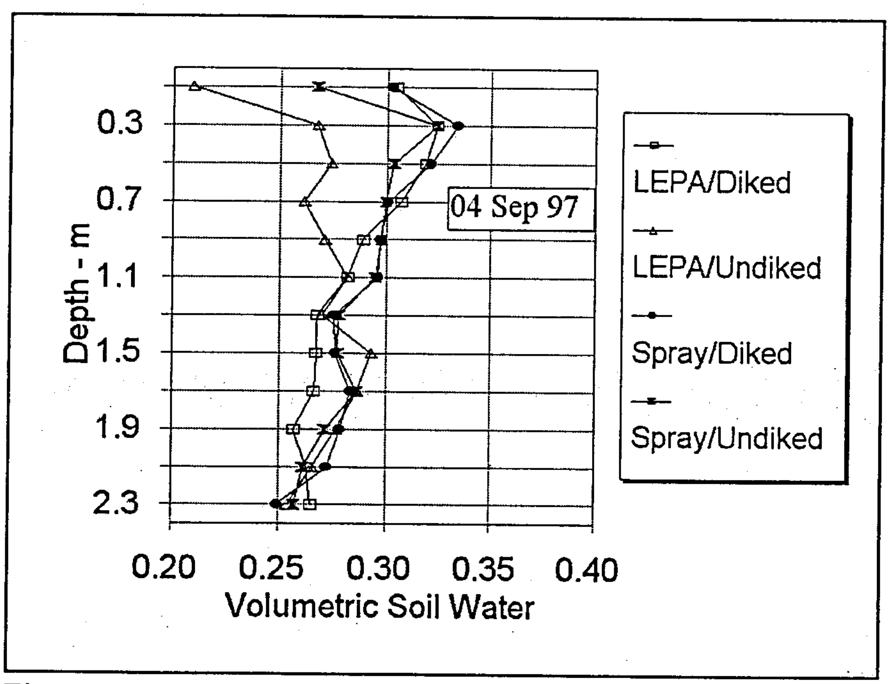

Figure 5. Soil water to the 2.3-m depth for the I_{100} plots on 4 Sep 97.

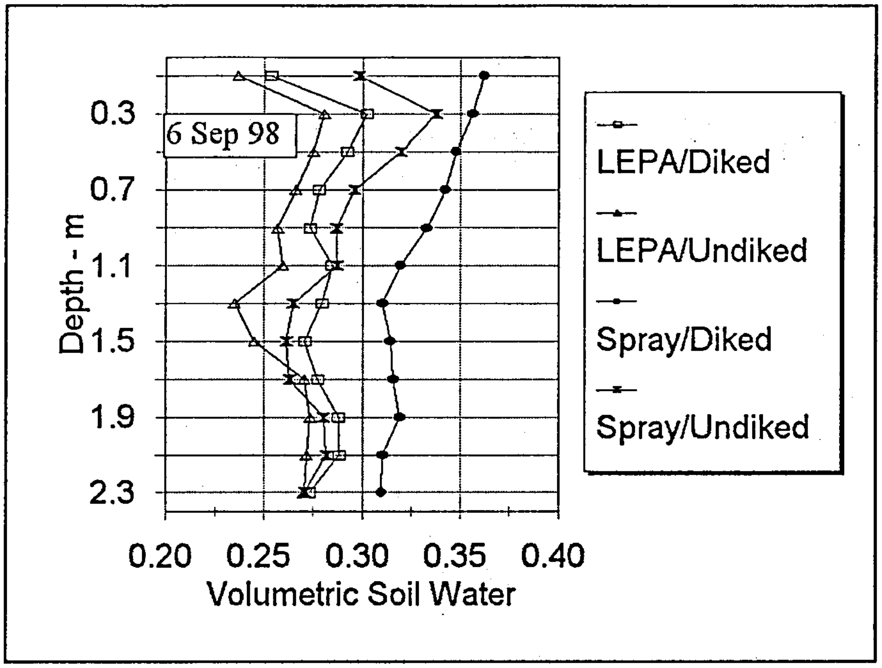

Figure 6. Soil water to the 2.3-m depth for the I_{100} plots on 6 Sep 98.

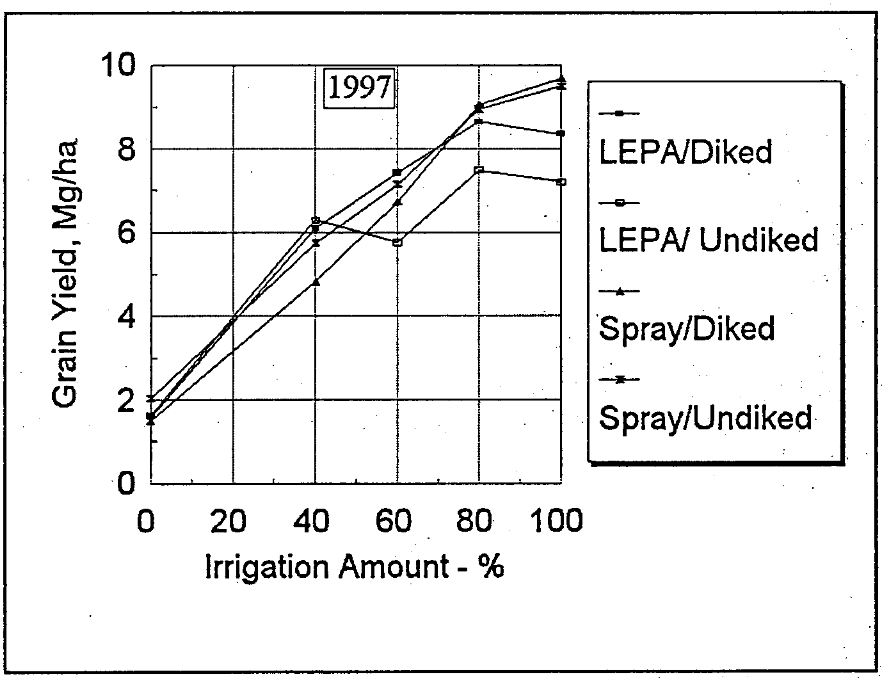

Figure 7. Grain sorghum yields for all treatments for 1997.

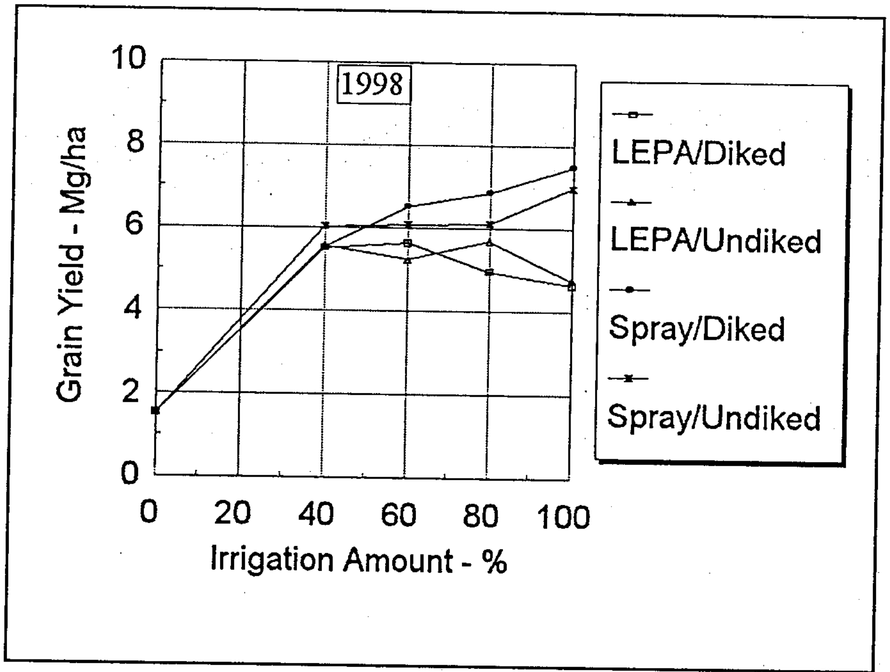

Figure 8.Grain sorghum yields for all treatments in 1998.